

## Chapter 2 Basic Switching Provisions

### 2-1. One-Line Diagrams

*a. General.* The development of a plant electrical one-line diagram should be one of the first tasks in the preliminary design of the plant. In evaluating a plant for good electrical system design, it is easy to discuss system design in terms of the plant's one-line electrical diagram. The relationship between generators, transformers, transmission lines, and sources of station service power are established, along with the electrical location of the associated power circuit breakers and their control and protection functions. The development of the plant one-line diagram and the switching arrangement required to implement the one-line may help determine the rating of generators and consequently the rating of the turbines and the size of the powerhouse. In developing plant one-line diagram alternatives, use should be made of IEEE C37.2 to aid those reviewing the alternatives.

*b. Evaluation factors.* Some factors to consider in evaluating one-line diagrams and switching arrangements include whether the plant will be manned or unmanned, equipment reliability, whether the plant will be used in a "peaking" versus a base load mode of operation, the need to maintain a minimum flow past the plant, or whether there is a restriction on the rate of change of flow past the plant. The base load mode implies a limited number of unit start-stop operations, and fewer breaker operations than would be required for peaking operation. Unmanned operation indicates a need for reliable protection and control, and simplicity of operation. If there are severe flow restrictions, coupled with a need for continuous reliable power output, it may be necessary to consider the "unit" arrangement scheme because it provides the minimum loss of generation during first contingency disturbances.

*c. Design characteristics.* In general, a good plant electrical one-line should be developed with the goal of achieving the following plant characteristics:

- (1) Safety and reliability.
- (2) Simplicity of operation.
- (3) Good technical performance.

(4) Readily maintainable (e.g., critical components can be removed from service without shutting down the balance of plant).

(5) Flexibility to deal with contingencies.

(6) Ability to accommodate system changes.

### 2-2. Plant Scope

*a. Extent of project.* When considering switching schemes, there are two basic power plant development scopes. Either the project scope will include a transmission-voltage switchyard associated with the plant or, electrically, the project scope ends at the line terminals of the high-voltage disconnect switch isolating the plant from the transmission line. Frequently, the Corps of Engineers project scope limit is the latter situation with the interconnecting switchyard designed, constructed, and operated by the Federal Power Marketing Agency (PMA), wielding the power or by the public utility purchasing the power through the PMA.

*b. Medium-voltage equipment.* Whether or not the scope includes a switchyard, the one-line development will involve the switching arrangement of the units, the number of units on the generator step-up (GSU) transformer bank, and the arrangement of power equipment from the generator to the low voltage terminals of the GSU transformer. This equipment is medium-voltage (0.6 kv-15 kV) electrical equipment. This chapter describes selection of appropriate switching schemes, including development of equipment ratings, economic factors, and operational considerations. Chapter 6, "Generator Voltage System," describes equipment types and application considerations in selecting the medium-voltage equipment used in these systems. Switching schemes for generating units and transformers may be of either the indoor or outdoor type, or a combination of both.

*c. High-voltage equipment.* When development does include a switchyard or substation, the same considerations apply in developing the generator voltage switching schemes described in paragraph 2-2b. Combined development does provide the opportunity to apply cost and technical trade-offs between the medium-voltage systems of the power plant and the high-voltage systems of the switchyard. Chapter 5, "High-Voltage System," describes switchyard arrangements, equipment and application considerations in developing the switchyard portion of the

one-line diagram. Switchyards are predominately outdoor installations although in special cases (e.g., an underground power plant) high-voltage SF<sub>6</sub> insulated equipment systems may find use.

## 2-3. Unit Switching Arrangements

*a. "Unit" arrangement.* A "unit" scheme showing outdoor switching of the generator and transformer bank as a unit on the high-voltage side only, is shown in Figure 2-1a. The unit scheme is well-suited to small power systems where loss of large blocks of generation are difficult to tolerate. The loss of a transformer bank or transmission line in all other arrangements would mean the loss of more than a single generation unit. Small power systems are systems not able to compensate for the loss of multiple units, as could occur using other arrangements. The "unit" scheme makes maintenance outages simpler to arrange and is advantageous where the plant is located near the high-voltage substation making a short transmission distance. This scheme, with a transformer and transmission line for each generator unit, tends to be

higher in first cost than schemes that have multiple generators on a single transformer and transmission line. Medium-voltage equipment for the unit systems includes bus leads from the generator to the GSU transformer and isolation disconnects for maintenance purposes.

### *b. Multiple unit arrangements.*

(1) In larger power systems, where loss of larger blocks of generation may be tolerable or where the plant is interconnected to an EHV grid (345 kV and above), two or more generators together with their transformer (or transformer bank) may be connected to one switchyard position. Some of the commonly used schemes are discussed in the following paragraphs. Refer to Chapter 3, "Generators" for discussion on the protection requirements for generator arrangements.

(2) Two generators may be connected to a two-winding transformer bank through Medium-Voltage Circuit Breakers (MVCBs) as shown on Figure 2-1b. This arrangement has the advantage of requiring a single transmission line for two units, rather than the two lines that would be required for a "unit" arrangement. This provides a clear savings in line right-of-way cost and maintenance. A single transformer, even though of higher rating, is also less costly than the two transformers that would be needed for a "unit" system. Again, the space requirement is also less than for two separate transformers. There are trade-offs: an MVCB for each generator is needed, the generator grounding and protection scheme becomes more complex, and additional space and equipment are needed for the generator medium-voltage (delta) bus. An economic study should be made to justify the choice of design, and the transformer impedance requirements should be evaluated if the power system is capable of delivering a large contribution to faults on the generator side of the transformer.

(3) For small generating plants, a scheme which connects the generators through MVCBs to the generator bus is shown in Figure 2-1c. One or more GSU transformers can be connected to the bus (one is shown), with or without circuit breakers; however, use of multiple transformers, each with its own circuit breaker, results in a very flexible operating arrangement. Individual transformers can be taken out of service for testing or maintenance without taking the whole plant out of service. The impedances of the transformers must be matched to avoid circulating currents. As noted above, the protection scheme becomes more complex, but this should be considered along with the other trade-offs when comparing this scheme with the other plant arrangements possible.

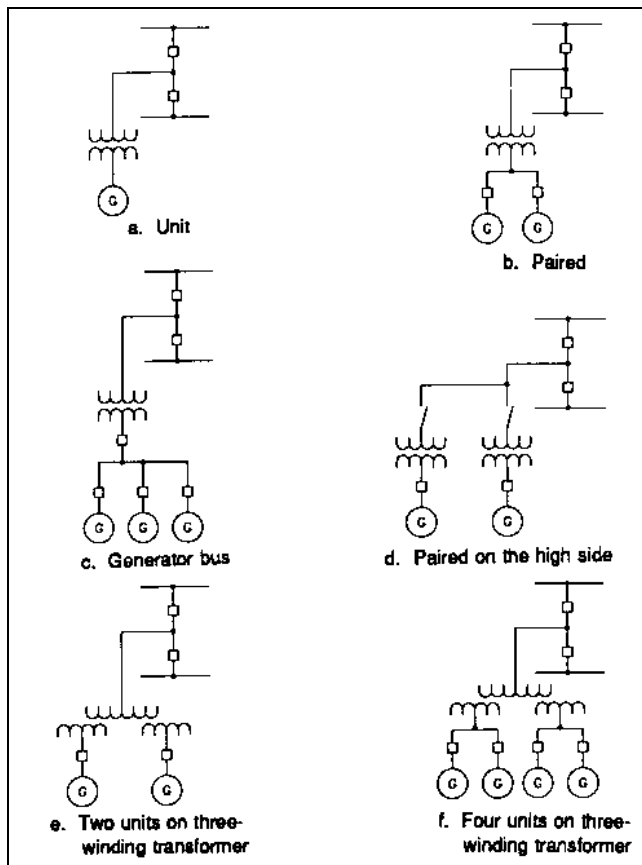


Figure 2-1. Main unit switching schemes

(4) Two or more generators can be connected to individual transformer banks through generator MVCBs with the transformers bused through disconnect switches on the high-voltage side as shown in Figure 2-1d. This arrangement has some of the advantages of the “unit” system shown in Figure 2-1a, and discussed above, along with the advantage of fewer transmission lines, which results in less right-of-way needs. There is some loss of operational flexibility, since transmission line service requires taking all of the units out of service, and a line fault will result in sudden loss of a rather large block of power. Again, needs of the bulk power distribution system and the economics of the arrangement must be considered.

(5) Two or more generators may be connected to a three-winding transformer bank as shown in Figure 2-1e and f. The generators would be connected to the two low-voltage windings through generator MVCBs. This arrangement allows specification of a low value of “through” impedance thus increasing the stability limits of the system and allowing the specification of a high value of impedance between the two low-voltage GSU transformer windings. This reduces the interrupting capacity requirements of the generator breakers. This scheme is particularly advisable when the plant is connected to a bulk power distribution system capable of delivering high fault currents. Again, transformer or line faults will result in the potential loss to the bulk power distribution system of a relatively large block of generation. Transformer maintenance or testing needs will require loss of the generating capacity of all four units for the duration of the test or maintenance outage. This scheme finds application where plants are interconnected directly to an EHV grid.

## 2-4. Substation Arrangements

*a. General.* High-voltage substation arrangements and application considerations are described in Chapter 5, “High-Voltage System.” High-voltage systems include those systems rated 69 kV and above. The plant switching arrangement should be coordinated with the switchyard arrangement to ensure that the resulting integration achieves the design goals outlined in paragraph 2-1c in a cost-effective manner.

*b. Substation switching.* Some plants may be electrically located in the power system so their transmission line-voltage buses become a connecting link for two or more lines in the power system network. This can require an appreciable amount of high-voltage switching equipment. The desirability of switching small units at generator voltage should nevertheless be investigated in such

cases. Chapters 5, “High-Voltage System” and 6, “Generator-Voltage System,” discuss switching and bus arrangements in more detail.

## 2-5. Fault Current Calculations

*a. General.* Fault current calculations, using the method of symmetrical components, should be prepared for each one-line scheme evaluated to determine required transformer impedances, generator and station switchgear breaker interrupting ratings, and ratings of disconnect switches and switchyard components. Conventional methods of making the necessary fault current calculations and of determining the required ratings for equipment are discussed in IEEE 242 and 399. A number of software programs are commercially available for performing these studies on a personal computer. Two of these programs are: ETAP, from Operation Technology, Inc., 17870 Sky-park Circle, Suite 102, Irvine, CA 92714; and DAPPER and A-FAULT, from SKM Systems Analysis, Inc., 225 S Sepulveda Blvd, Suite 350, Manhattan Beach, CA 90266.

*b. Criteria.* The following criteria should be followed in determining values of system short-circuit capacity, power transformer impedances, and generator reactances to be used in the fault current calculations.

(1) System short-circuit capacity. This is the estimated maximum ultimate symmetrical kVA short-circuit capacity available at the high-voltage terminals of the GSU transformer connected to the generator under consideration, or external to the generator under consideration if no step-up transformer is used. It includes the short-circuit capacity available from all other generators in the power plant in addition to the short-circuit capacity of the high-voltage transmission system. System short-circuit capacity is usually readily available from system planners of the utility or the PMA to which the plant will be connected.

(2) Calculating system short-circuit capacity. The transmission system short-circuit capacity can also be calculated with reasonable accuracy when sufficient information regarding the planned ultimate transmission system is available, including the total generating capacity connected to the system and the impedances of the various transmission lines that provide a path from the energy sources to the plant.

(3) Estimating power system fault contribution. When adequate information regarding the transmission system is unavailable, estimating methods must be used.

In all cases, the system short-circuit capacity for use in the fault current calculations should be estimated on a conservative basis, i.e., the estimate should be large enough to allow for at least a 50-percent margin of error in the system contribution. This should provide a factor of safety, and also allow for addition of transmission lines and generation capacity not presently planned or contemplated by system engineers and planners. Only in exceptional cases, such as small-capacity generating plants with only one or two connecting transmission lines, should the estimated ultimate system short-circuit capacity be less than 1,000 MVA.

(4) Power transformer impedances.

(a) Actual test values of power transformer impedances should be used in the fault calculations, if they are available. If test values are not available, design values of impedance, adjusted for maximum IEEE standard minus tolerance (7.5 percent for two-winding transformers, and 10 percent for three-winding transformers and auto-transformers) should be used. Nominal design impedance values are contained in Table 4-1 of Chapter 4, "Power Transformers." For example, if the impedance of a two-winding transformer is specified to be 8.0 percent, subject to IEEE tolerances, the transformer will be designed for 8.0 percent impedance. However, the test impedance may be as low as 8.0 percent less a 7.5-percent tolerance, or 7.4 percent, and this lower value should be used in the calculations, since the lower value of impedance gives greater fault current.

(b) If the impedance of the above example transformer is specified to be not more than 8.0 percent, the transformer will be designed for 7.44 percent impedance,

so that the upper impedance value could be 7.998 percent, and the lower impedance value (due to the design tolerance) could be as low as 6.88 percent, which is 7.44 percent less the 7.5 percent tolerance, which should be used in the calculations because the lower value gives a higher fault current. Using the lower impedance value is a more conservative method of estimating the fault current, because it anticipates a "worst case" condition. Impedances for three-winding transformers and auto-transformers should also be adjusted for standard tolerance in accordance with the above criteria. The adjusted impedance should then be converted to an equivalent impedance for use in the sequence networks in the fault current calculations. Methods of calculating the equivalent impedances and developing equivalent circuits are described in IEEE 242.

(5) Generator reactances. Actual test values of generator reactances should also be used in the calculations if they are available. If test values are not available, calculated values of reactances, obtained from the generator manufacturer and adjusted to the appropriate MVA base, should be used. Rated-voltage (saturated) values of the direct-axis transient reactance ( $X'_d$ ), the direct-axis subtransient reactance ( $X''_d$ ), and the negative-sequence reactance ( $X_2$ ), and the zero-sequence reactance ( $X_0$ ), are the four generator reactances required for use in the fault current calculations. If data are not available, Figure 3-2 in Chapter 3, "Generators," provides typical values of rated-voltage direct-axis subtransient reactance for water-wheel generators based on machine size and speed. Design reactance values are interrelated with other specified machine values (e.g., short-circuit ratio, efficiency) so revised data should be incorporated into fault computations once a machine has been selected.